Sex-Dependent Components of the Analgesia Produced by Athletic Competition

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Abstract: Competing in various athletic events (track meet, basketball game, or fencing match) can produce analgesia to cold pressor stimuli in male and female college athletes compared with baseline assessments. This competition-induced analgesia has been attributed to the stress associated with competition, which has components related to both physical exercise and the cognitive aspects of competing. This study evaluated the analgesic effect of exercise-related stress, and that caused by the cognitively stressful components of competing independent of exercise. Cold pressor pain ratings were assessed after competition in a track meet and after treadmill exercise or sedentary video game competition in both athletes and nonathletes. As expected, competing in athletics resulted in a decrease in cold pressor ratings in both male and female athletes. Independent of athletic status, treadmill running induced analgesia in women, but not in males, whereas sedentary video game competition produced analgesia in men, but not in women. These findings suggest that different components of the competitive athletic experience might be responsible for the analgesic effects in a sex-dependent manner.

Key words: *Sex differences, athletic competition–induced analgesia, exercise, cold pressor pain.*

The central nervous system contains circuitry for the inhibition of pain sensation, and a natural trigger for this endogenous analgesia is environmental stress.[1] The production of stress-induced analgesia (SIA) in laboratory animals is well documented, and a multitude of experimental paradigms have been developed for the detailed study of analgesia pathways in these subjects.[2] A limited number of studies have documented reliable pain modulation in human subjects faced with a variety of experimental situations that might be considered stressors.[3,4]

In a recent study conducted by this laboratory, male and female college athletes experienced a marked reduction in pain intensity and unpleasantness ratings on the cold pressor test after participation in a track race, a basketball game, or a fencing bout compared with their own ratings assessed both 2 days before and two days after the event.[5] The pain ratings of noncompeting, nonathlete controls did not change across 3 similarly spaced assessments. This demonstration of competition-induced analgesia is limited by our inability to separate the cognitive mindset associated with competition from the physical exercise component of the competitive experience.

Psychological manipulations can result in activation of pain modulatory pathways, as it is well known that placebos, anxiety, distraction, and hypnotic suggestion can alter subjects' reports of pain.[6-8] The modulation that results from such psychological factors might be excitatory or inhibitory, resulting in enhanced or diminished pain perception. For example, anxiety associated with dental examinations tends to lower pain thresholds during treatment and increase patients' reports of unpleasantness of treatment.[6] Placebos and hypnosis, on the other hand, can be highly effective as analgesics,[7,8] suggesting activation of endogenous pain inhibitory controls by psychological factors. Thus, the pain modulation previously observed to result from athletic competition might have been activated by the stress associated with such competition (including cognitive components such as anticipation, motivation, distraction, and fear).

Exercise outside of a competition setting has been shown to increase pain thresholds, most reliably after high-intensity exercise (see O'Connor and Cook[9] for review); however, the generalizability of this phenomenon across pain assessment methods and experimental settings is uncertain,[9] and it is common for studies of this sort to lack repeated-testing controls.[10] Exercise-induced analgesia has not been reliably shown on the cold pressor test,[10-12] the tool used to assess pain in our previous experiment. Thus, exercise-induced analgesia might not be the mechanism underlying the reductions in cold pressor pain noted in our prior experiment. We

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attributed our previous findings of athletic competition-induced analgesia, at least in part, to the cognitive aspects of competition stress, rather than solely to an effect of exercise.[5]

The current study was designed to separately assess the pain inhibitory effects of the stressful components of an athletic competition: the cognitive stress associated with competing against another individual or oneself (in an effort to improve performance), and the physical exercise associated with the activity. Therefore, the analgesic effects on cold pressor pain ratings in male and female track athletes were compared after (1) competing in a track meet, (2) competing in a head-to-head video auto racing game, and (3) running for a fixed period of time on a treadmill. Pain ratings of nonathlete controls also were assessed in the laboratory conditions (video game competition and treadmill exercise) at the same intervals. It is hypothesized that because treadmill running at or near practice intensities is not a stressful experience for trained track athletes, no pain modulatory effects will be observed in these subjects, but consistent with other studies of exercise-induced analgesia, treadmill running in nonathletes might produce analgesia. A second hypothesis is that sedentary video game competition might access the competitive cognitive mindset of a trained runner and produce analgesia only in the trained athletes. A track meet condition (for athletes only) also is included as a replication and validation of the results observed in our previous study.[5]

Methods

Subjects

Forty-one members (19 men, 22 women) of the Haverford College varsity track team (NCAA division III) and 22 nonathletes (11 men, 11 women) recruited from the campus population were participants in the study. The nonathlete subject pool was limited to those individuals who did not participate in any organized college teams or club sports that trained at a level comparable with varsity teams. These sample sizes were deemed appropriate (ie, experimental power of at least 0.80) after power calculations that used the difference between cold pressor ratings on the competition and baseline days in our last study as an estimate of the treatment effect and the within groups mean squares value ($MS_{S/A}$) from that study as an estimate of the population error variance.[13] Subjects were given the opportunity to be entered in a lottery, in which 6 prizes of $20 were awarded to randomly drawn participants at the end of the study, or to receive course credit for participation in a psychology experiment (available only to those enrolled in the psychology course). Procedures were explained to all subjects and informed consent was obtained before experimental testing began. Procedures were approved by the Haverford College Human Subjects Committee before the experiment and conformed to the ethical guidelines set forth by the 1975 Declaration of Helsinki.

Apparatus

Pain Measures

The main pain measure was the cold pressor test. The cold pressor test consisted of subjects placing their nondominant arms in a plastic container (height, 44 cm; diameter, 28 cm) filled with ice water maintained between 0˚C to 2˚C for a maximum time period of 90 seconds. A cylindrical mesh screen (diameter, 13 cm) was placed in the center of the container to prevent ice from contacting the skin. Every 15 seconds, subjects were asked to rate the pain on the unbounded logarithmic version of the Gracely Box Scales for both pain intensity and unpleasantness.[14] Unpleasantness and intensity scales were presented in random order each time the subjects were asked to report ratings. Subjects were told they could withdraw their arms at any time if the pain became unbearable (at which time, they were assigned the maximum pain ratings for the remainder of the test).

Radiant heat pain threshold was evaluated as a secondary measure, and was determined by the latency of a withdrawal response from the heat source (Ugo Basile radiant heat tail-flick apparatus, adapted for human use) on both the volar surface of the forearms and the fingertips (excluding the thumbs). Subjects alternated placing their fingers or forearms over the radiant heat source and were instructed to remove their finger or arm when the stimulus became painful. Two stimulus intensities were chosen to produce latencies comparable with our previous study. Stimulus intensities were randomly varied outside of the subjects' view between each assessment. Four withdrawal latencies were recorded at each setting for both finger and forearm body loci. Because of equipment malfunction, withdrawal latencies were not assessed in the track meet condition.

Skin Temperature

Because surface skin temperature fluctuations might influence withdrawal latency from radiant heat,[15] skin temperature was measured during both the baseline session and after participation in each of the experimental activities (track meet competition, video game, treadmill run). Three separate skin temperature measurements were taken before withdrawal latencies along the inner surface of the arm, using a noncontact infrared thermometer (Kent Scientific Model C-1600MP). An average skin temperature measure was computed and considered in analyses of heat withdrawal data (described subsequently in this article).

Mood

Subjective measurements of stress, anxiety, fatigue, arousal, anger, and attention were assessed using the Stress Symptoms Ratings Scale (SSR), which consisted of paired opposite descriptor terms anchoring the ends of a 10-cm visual analog scale (VAS). The following adjective pairs were used to assess ratings on the mood subscales: arousal (lively-unmotivated, awake-drowsy); stress (tense-relaxed, stressed-at ease); anxiety (ner-

vous-calm, jittery-tranquil); anger (irritable-agreeable, annoyed-patient); fatigue (tired-energetic, fatigued-forceful); and attention (focused-distracted, attentive-scattered). SSR values were assessed after pain measurements.[16] This mood ratings scale has been used previously in human experimental studies of stress, and has shown to be associated with the immunologic and neurohormonal markers of acute stress experience.[16]

Procedures

All subjects were tested on 2 occasions, a baseline session and an activity session (activity refers to the track meet, video game, or exercise conditions). There was no difference in pain ratings between the first baseline day and the second baseline day (2 days before and after the athletic competition, respectively) in our previous study[5]; thus, only one baseline session was used in this study. The order of testing days was counterbalanced between subjects, such that some subjects participated in the baseline session first, whereas others experienced the activity session before the baseline assessment. During the baseline session, and in the 2 laboratory conditions, pain responses (and associated measures) were obtained in a laboratory in the Psychology Department at Haverford College. During the baseline session, SSR values, skin temperature, radiant heat withdrawal latencies, and cold pressor ratings were assessed as described previously. Subjects of both sexes were tested by 1 of 2 female experimenters or a male experimenter; the gender of the experimenter was held constant for each subject across testing days. On the activity day, procedures differed depending on the condition to which the subjects were randomly assigned as described (subsequently in this article) in detail for each condition, but pain testing always took place immediately after participation in the activity.

Sedentary Competition

Twelve athletes (6 men, 6 women) and 12 nonathletes (6 men, 6 women) were assigned to the sedentary competition condition. Same sex pairs of subjects competed against one another on a video auto racing game using hand-held controls. Each subject controlled 1 of 2 cars in a split-screen configuration, and each subject's screen displayed the same view of the race. Before competition, subjects were introduced to the game and controls and were given 2 minutes to practice using the controls. A monetary incentive was provided to the participants in the video game to elicit a desire to compete. Both subjects were tested immediately after the video game; one subject completed SSR forms and skin temperature measurements while the other provided heat withdrawal latencies. Because of the lowering of skin temperature by the cold pressor test (which could potentially influence withdrawal latencies), both subjects were administered the radiant heat test before the cold pressor test.

Exercise Condition

Ten athletes (5 men, 5 women) and 10 nonathletes (5 men, 5 women) were assigned to the exercise condition. After a 2-minute warm-up period of brisk walking, subjects ran for 10 minutes on a standard exercise treadmill while maintaining 85% maximal heart rate computed according to the following formula:

$$(220 - \text{age}) \times 0.85$$

This method of computing maximum heart rate is widely used in athletic training as well as cardiovascular research,[17] and 85% of age-adjusted maximal heart rate was chosen so that the exercise would be physically taxing for the subjects. For college-age subjects (age 17 to 22), this target heart rate was 160 to 170 beats per minute (BPM). Three ECG electrodes were attached to the torso of each subject in a standard configuration surrounding the heart. Electrodes were connected by a 10-ft lead to a Biopac physiologic recording device. Heart rate (in BPM) was displayed on a computer monitor in view of the subject so that their level of exertion could be adjusted to maintain the target heart rate. Withdrawal latencies, SSR values, cold pressor ratings, and skin temperature were assessed after the treadmill run.

Track Meet

Nineteen athletes (9 men and 10 women) were assigned to the track meet condition. Subjects were tested on site during the athletic event, in the Haverford College Field House. The testing station was separated from the performing arena by a screen for privacy. Immediately after a designated race (subjects were informed before the meet of their designated event), each subject reported to the testing station and provided cold pressor ratings, SSR values, and skin temperature measurements.

Data Analysis

Cold pressor ratings over the 90-second exposure were summed to obtain a measure of pain intensity and unpleasantness for each subject. A separate analysis was conducted using the 6 cold pressor ratings as levels of a repeated measures variable to assess sex or athletic status differences during the time course of cold pressor exposure. This repeated measures analysis was conducted only for the lab conditions, because there were no counterpart nonathletes participating in the track meet. Withdrawal latencies obtained for each body site were averaged to provide a single latency for forearm or finger at both stimulus intensities. The 3 skin temperature ratings also were averaged. A composite score for each of the SSR subscales was computed.

To assess the effects of participating in the track meet (athletes only), 2×2 mixed-factorial analyses of variance (ANOVAs) were conducted on cold pressor ratings and SSR data, with sex as a between-groups

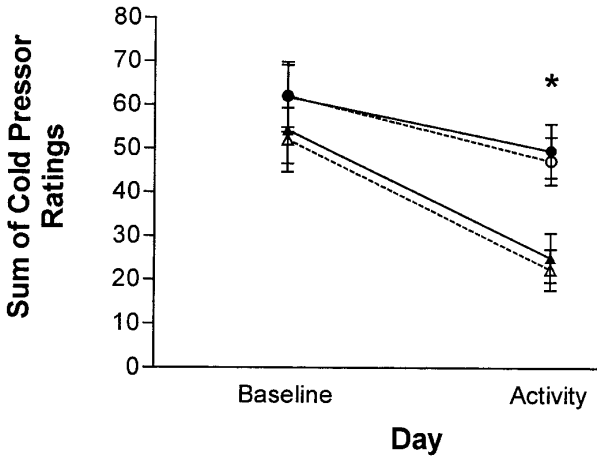

Figure 1. Cold pressor intensity and unpleasantness ratings of athletes participating in the track meet condition on the baseline day (2 days before or 2 days after the track meet) and the activity day (immediately after track event). * Pain ratings were significantly decreased after the track event compared with baseline values in both sexes and on both pain scales. Female intensity, ●; Male intensity, ▲; female unpleasantness, ○; male unpleasantness, △.

variable and day (baseline day versus track meet) as a within-subjects variable. This analysis was followed by a $2 \times 2 \times 2 \times 2$ mixed-factorial ANOVA on cold pressor, withdrawal latency, mood, and skin temperature data obtained from all subjects participating in the laboratory conditions, with sex, athletic status, and activity (video game or treadmill) as between-groups conditions and day as a within-subjects variable. An additional analysis was conducted to determine if gender of the experimenter impacted on cold pressor pain report. Significant *F*-values were followed by Fisher least significant difference (LSD) post hoc tests when appropriate. Level of significance for all tests was set at 0.05.

Results

Athletes-Only Analyses (Track Meet Condition)

Cold Pressor Ratings

A main effect of day was observed on both pain intensity ($F[1,19] = 21.66$; $P = .0001$) and unpleasantness ($F[1,19] = 21.87$; $P = .0001$) ratings. Participating in a track meet significantly reduced cold pressor ratings compared with the baseline day (Fig 1). The sex $\times$ day interaction approached significance for intensity ($F[1,19] = 3.6$; $P = .07$), suggesting that the decrease in cold pressor ratings was larger for male subjects than for female subjects.

SSR Data

Significant effects of athletic competition were observed on the anxiety ($F[1,18] = 5.63$; $P = .02$) and fatigue ($F[1,18] = 4.93$; $P = .03$) SSR subscales with subjects reporting more anxiety (Fig 2) and more fatigue after competition compared with baseline reports. In addition, a significant sex $\times$ day interaction on the anger dimension ($F[1,18] = 6.49$; $P = .02$), indicated that men, but not women, reported increased anger ratings after athletic competition (Fig 2).

Lab Condition Analyses (Treadmill Exercise and Video Game Competition)

Cold Pressor Ratings

An overall significant effect of sex was noted for both pain intensity ($F[1,32] = 4.31$; $P = .04$) and unpleasantness ($F[1,32] = 5.64$; $P = .02$) ratings with men providing lower ratings overall than women, as shown in Table 1. A significant main effect of athletic status also was observed ($F[1,32] = 6.76$ and $P = .01$ for intensity; $F[1,32] = 6.77$ and $P = .01$ for unpleasantness) with athletes providing overall lower ratings than nonathletes (see Table 1 for mean cold pressor ratings of male and female athletes and nonathletes). A main effect of day ($F[1,32] = 6.30$ and $P = .01$ for intensity; $F[1,32] = 9.39$ and $P = .004$ for affect) indicated that, overall, lower pain ratings were given on the activity day than on the baseline day.

However, this main effect of day was condition- and sex-dependent, as evidenced by a significant 3-way interaction ($F[1,32] = 14.44$ and $P = .0006$ for intensity; $F[1,32] = 9.45$ and $P = .004$ for unpleasantness) among sex, condition, and the within-subjects variable (Fig 3). Post hoc analysis revealed that video game competition significantly reduced pain ratings compared with baseline in men ($P = .0001$ for intensity; $P = .006$ for unpleasantness) but not in women ($P = .19$ for intensity; $P = .51$ for unpleasantness). Conversely, treadmill exercise significantly reduced pain ratings in women ($P = .05$ for intensity; $P = .002$ for unpleasantness) but not in men ($P = .98$ for intensity; $P = .50$ for unpleasantness). These changes in pain ratings were unaffected by athletic status.

Analysis of the cold pressor time course revealed several effects. Only cold pressor intensity ratings are reported here, but the pattern of effects was the same for the unpleasantness scale. As in the analysis of summed data, there was an overall sex effect ($F[1,85] = 6.98$; $P = .009$; women greater than men), and a main effect for athletic status ($F[1,85] = 14.03$; $P = .0003$; nonathletes greater than athletes). In addition, a main effect of time ($F[5,425] = 60.34$; $P < .0000001$) indicates that in general, cold pressor ratings increase over the 90-second time course; however, a significant athletic status $\times$ time interaction ($F[5,425] = 5.47$; $P = .00006$) qualifies this increase in ratings. Ratings significantly increased at each time point compared with the prior rating until the 75-second time point in nonathletes, whereas in athletes, ratings did not increase as drastically as in nonathletes, regardless of sex or condition (baseline versus activity). In athletes, ratings did not significantly increase after the second time point (30 seconds). Although nonathlete ratings were significantly

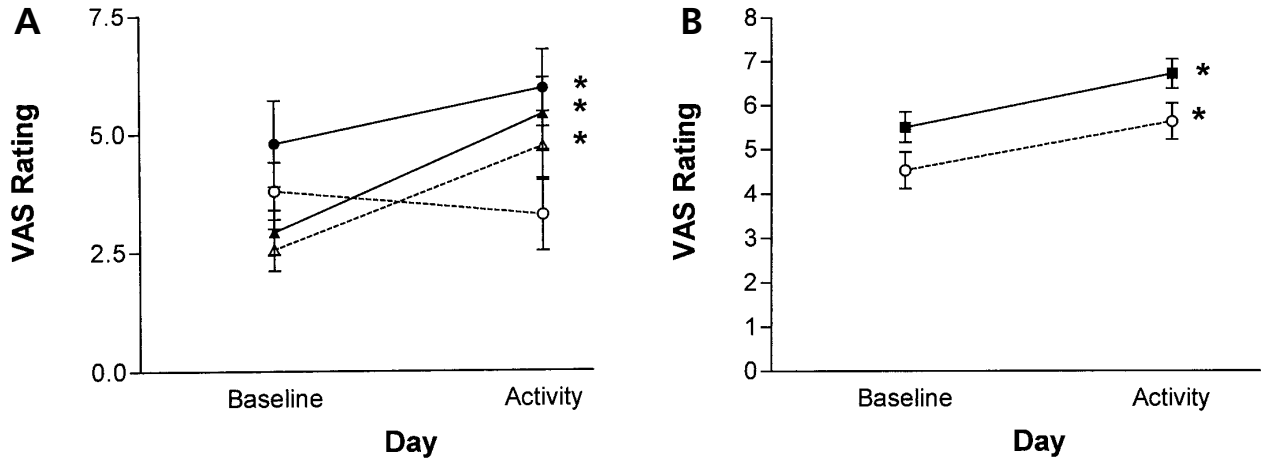

Figure 2. (A) Stress symptoms ratings (SSR) visual analog score (VAS) measurements for anxiety and anger subscales in male and female athletes participating in the track meet. *Anxiety increased in both sexes on the track meet day compared with baseline assessment; anger increased only in male subjects. Female anxiety, ●; male anxiety, ▲; female anger, ○; male anger, △. (B) SSR VAS measurements for anxiety and arousal subscales in male and female subjects participating in the laboratory conditions. *Significant increases in anxiety and arousal ratings on activity day (exercise or video game competition) compared with baseline values (assessed 2 days before or 2 days after activity day). Arousal, ■; anxiety, ○.

higher than athlete ratings even at the first time point, the difference between the groups diverged greatly by the third time point (45 seconds).

SSR Data

Ratings of both arousal (F[1,31] = 4.58; P = .04) and anxiety (F[1,31] = 4.67; P = .03) increased on the activity day compared with the baseline day. Decreases in anger ratings on the activity day approached significance (F[1,31] = 3.77; P = .06).

Heat Withdrawal Data

Significant main effects of sex (longer latency in men compared with women) were observed on withdrawal latency data for the fingertip loci (F[1,29] = 4.77 and P = .03 for low intensity; F[1] = 12.14 and P = .001 for high intensity), but no significant sex effects were observed for the forearm loci. Withdrawal latencies on the fingertips significantly decreased (indicating increased pain sensitivity) on the activity day compared with the baseline day in the treadmill exercise condition but not in the video game competition, as indicated by a significant condition × day interaction (F[1,29] = 8.82 and P = .005 for low intensity; F[1,30] = 6.97 and P = .01 for high intensity) followed by post-hoc analyses. The difference between withdrawal latencies on baseline and activity days was significant for the exercise condition (P = .003 for both intensities), but not for the video game competition (P = not significant (ns) for both intensities) averaged across athletes and nonathletes of both sexes (Fig 4). There was neither significant main effect of day for withdrawal latencies on the forearm, nor any significant interactions.

Skin Temperature

There were no differences in skin temperature between baseline and activity days in any of the laboratory conditions or at the track meet.

Experimenter Gender

Subjects were separated by the gender of the experimenter (same as the subject, or opposite) and sum of the cold pressor pain ratings on both the intensity and unpleasantness scales were compared between same and opposite sex experimenter groups. Because no nonathlete women were tested by an opposite sex experimenter (this imbalance was caused by the fact that there was only one male experimenter, whereas

Table 1. Sex and Athlete Status Differences in Pain Report

	Female[*]		*Male*	
	Athlete	*Nonathlete*[†]	*Athlete*	*Nonathlete*[†]
Intensity	66.00 ± 6.9 (18)	83.22 ± 4.8 (22)	47.66 ± 5.18 (18)	71.59 ± 5.9 (22)
Unpleasantness	68.83 ± 6.8 (18)	80.54 ± 4.3 (22)	45.72 ± 4.6 (18)	71.68 ± 5.7 (22)

NOTE. Sex and athletic status differences in mean (± standard error of the mean) cold pressor ratings (baseline and activity day ratings included) on both pain intensity and unpleasantness scales among subjects participating in the laboratory conditions. Numbers in parentheses indicate the number of observations contributing to each mean.

[*]Significantly higher ratings overall in females than in males (effect size [ω^2] = 0.10 for intensity; 0.14 for unpleasantness).

[†]Significantly higher ratings overall in nonathletes than in athletes (ω^2 = 0.17 for intensity; 0.18 for unpleasantness).

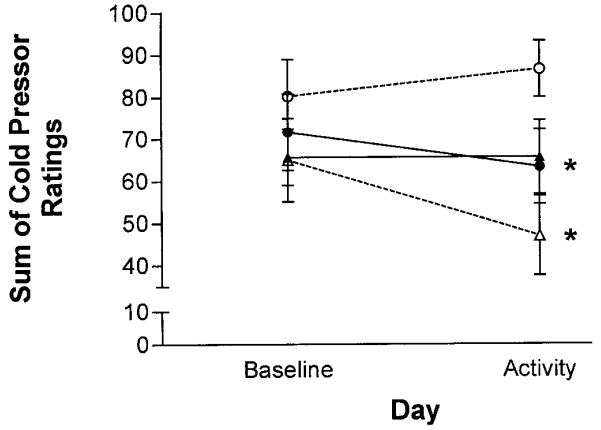

Figure 3. Cold pressor intensity ratings of subjects participating in the laboratory conditions (exercise or sedentary video game competition) on both the baseline day (2 days before or 2 days after participation in the laboratory condition) and activity day (immediately after treadmill run or video game). * Significant decreases compared with baseline values on activity day (exercise condition in women, sedentary competition in men). Female exercise, ●; male exercise, ▲; female sedentary, ○; male sedentary, △.

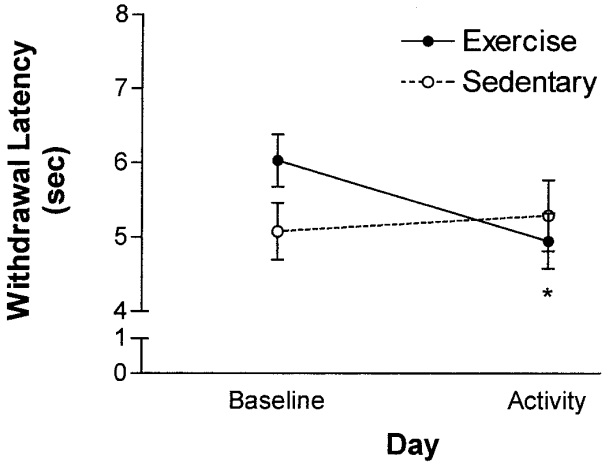

Figure 4. Withdrawal latencies (at low intensity setting on radiant heat device) of subjects participating in laboratory conditions. *Significant decrease in finger withdrawal latency in male and female subjects after the treadmill exercise compared with baseline latencies (assessed 2 days before or 2 days after exercise). No changes from baseline latencies were noted in subjects participating in the sedentary competition condition. Exercise, ●; sedentary, ○.

there were 2 female experimenters involved in the study), 2 analyses were conducted, one for female subjects and one for male subjects. The analysis for male subjects included athletic status as an independent variable; the female subjects analysis was conducted using data from female athletes only (some tested by a same sex experimenter, others tested by an opposite sex experimenter). As shown in Table 2, a significant main effect of experimenter gender in the women-only analysis indicated that for both pain scales, female subjects reported significantly lower pain ratings to a male experimenter than to a female experimenter ($F[1,38] = 5.76$ and $P = .02$ for intensity; $F[1,38] = 5.79$ and $P = .02$ for unpleasantness). Male subjects' pain reports did not depend on experimenter gender (see Table 2 for mean cold pressor ratings separated by subject gender and experimenter gender).

Discussion

The results of this study support previous findings of athletic competition-induced analgesia; cold pressor pain intensity and unpleasantness ratings significantly decreased following participation in a competitive track meet compared to subjects' own baseline values reported 2 days before or 2 days after the meet. The striking gender differences revealed in the laboratory conditions in the current study suggest further interpretation of this effect. Athletic competition likely produces analgesia because it is stressful, both psychologically and physically (ie, arousing sympathetic nervous system activity), in both male and female subjects. However, the present results suggest that the reasons that athletic competition might be stressful (and, therefore, analgesia-producing) might differ between the sexes. Treadmill running reduced cold pressor pain ratings in women only, whereas competing against another individual in a sedentary video game task induced an analgesic state in men only. The decrease in cold pressor ratings induced by exercise and sedentary competition in women and men, respectively, is comparable in size to that induced by athletic competition (see Fig 5). Thus, SIA induced by athletic competition might be caused by different stressful components of the experience depending on sex, exercise in female subjects, and competition in male subjects.

These conclusions are based on the robust sex differences found in the ability of the different laboratory manipulations to produce pain inhibition. However, the degree to which these gender effects extend to other exercise or sedentary competition situations is not known. Although the sedentary competition used in this study, a video game, did not produce analgesia in women, this negative effect does not suggest that women are wholly noncompetitive. The cognitive mindset associated with competition stress might, indeed, be capable of eliciting analgesia in women. However, in this study, video game competition did not sufficiently activate analgesia pathways in women, because these subjects did not experience any changes at all in cold pressor ratings after video game competition. Although both sexes reported equal levels of arousal on the mood questionnaires after the video game, observation of the subjects suggests that the men were much more engaged in the task than the women. Past research investigating sex differences in video game usage suggests that video games are less popular with women; therefore, women are less skilled and report more competitive anxiety and exhibit lower performance than males.[18] Thus, the experience of

Table 2. Experimenter Gender Effects on Pain Report

	Female Subjects		*Male Subjects*	
Exp. Gender	*Athlete*	*Nonathlete*	*Athlete*	*Nonathlete†*
Same	I: 61.48 ± 2 (35)*	I: 83.32 ± 4.8 (24)	I: 43.42 ± 5.8 (19)	I: 73.22 ± 8.7 (9)
	U: 61.31 ± 3.8 (35)*	U: 80.54 ± 4.3 (24)	U: 41.63 ± 5.4 (19)	U: 74.44 ± 7.0 (9)
Opposite	I: 33.6 ± 8.5 (5)	—	U: 35.2 ± 10.4 (5)	I: 46.07 ± 6.0 (15)
	U: 42.07 ± 5.4 (15)	—	I: 70.40 ± 8.4 (13)	U: 69.76 ± 8.5 (13)

NOTE. Cold pressor intensity (I) and unpleasantness (U) ratings of male and female subjects separated by the gender of the experimenter to which the subject reported ratings. Because there were no nonathlete female subjects tested by a male experimenter, statistical comparisons were conducted separately for each sex, with only female athletes contributing data to the female analysis. Numbers in parentheses indicate the number of subjects contributing to each mean.

* Significant difference between female athletes reporting to same versus opposite sex experimenters on both pain rating scales (effect size [ω^2] = 0.13 for intensity; ω^2 = 0.14 for unpleasantness).

† Significantly higher ratings in nonathlete males than athlete males (ω^2 = 0.23 for intensity; ω^2 = 0.36 for unpleasantness).

video game competition might not have been as rewarding or engaging for the women, thereby failing to evoke a personal investment in the game. The men in this study were aroused and engaged by the video game competition and were highly motivated to participate in the game, and these were the subjects who exhibited the most analgesia after this task. These findings support our hypothesis that competition in personally meaningful tasks (such as an athletic event, or video games for men) is capable of activating SIA. A challenge for future studies is to design a sedentary competition task that both women and men find universally engaging.

That a short-duration treadmill run produced analgesia in women only, independent of athletic status, was an unexpected finding, particularly in female track athletes who frequently train at much higher intensity levels than required by the treadmill task. Female athletes and nonathletes reported less pain on the cold pressor test after exercise compared with baseline levels. Thus, the athletic-competition analgesia displayed by women after a track event might simply reflect the phenomenon of exercise-induced analgesia that has been reported (albeit inconsistently) in the literature.[9] That similar effects of exercise on pain ratings were not observed in men suggests that exercise in this study was not a stressful experience and therefore was incapable of eliciting SIA in these subjects. Both men and women have shown plasma β-endorphin release to a longer duration treadmill run than we used in the current study.[19] However, the threshold for exercise-induced activation of endogenous opioid systems in human subjects is unknown, and might differ between the sexes. The hypothalamic-pituitary-adrenal (HPA) axis shows differential responsiveness to exercise stress in men and women, with women mounting a larger glucocorticoid response than men.[20] Increasing the difficulty or duration of the treadmill exercise might

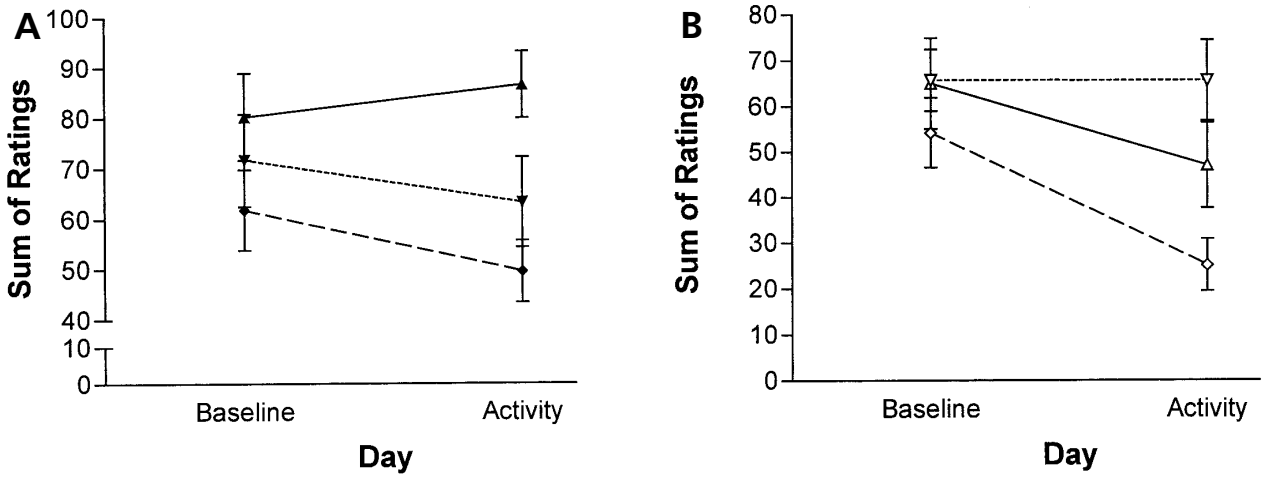

Figure 5. Cold pressor intensity ratings of female (A) and male (B) subjects across all 3 activity conditions (track meet, exercise, sedentary competition) compared with baseline values (assessed 2 days before or 2 days after activity). In female subjects, the decrease in cold pressor ratings from baseline observed in the exercise condition is similar in magnitude to that of female athletes running in a track event. In male subjects, the decrease in cold pressor ratings from baseline observed in the sedentary competition condition is similar in magnitude to that of male athletes running in a track event. Female track meet, ◆; female exercise, ▼; female sedentary, ▲; male track meet, ◇; male exercise, ▽; male sedentary, △.

result in exercise-induced analgesia in male subjects as well as female.

In our previous study, we found that in both men and women, withdrawal latencies to noxious heat decreased (indicating hyperalgesia) on the fingertips but increased (indicating analgesia) on the forearms after athletic competition in track athletes.[5] However, because we did not assess skin temperature in that study, changes in withdrawal latency could be secondary to skin temperature changes induced by running in a track meet, although we presented arguments to suggest that this was not the case. Although we could not measure withdrawal latency at the track meet (because of equipment malfunction), forearm skin temperature did not change from baseline values. Thus, the changes in withdrawal latency observed on the forearm in our previous study are unlikely to be secondary to skin temperature changes induced by running in a track meet. All subjects showed a hyperalgesic effect of exercise on the fingertips, although it is unknown whether skin temperature on the fingertips changed in response to exercise (no temperature changes were observed on the forearm after exercise). Although we have not ruled out the possibility that the hyperalgesic effect of exercise on the fingertips is secondary to potential skin temperature alterations, we are intrigued by this hyperalgesic effect and will continue to investigate this phenomenon in future studies coupled with appropriate measures of fingertip temperature.

This apparent hyperalgesic effect of exercise on the fingertips was noted in subjects of both sexes, although exercise only induced cold-pressor analgesia in women. In our previous study, running in a track meet produced this same pattern of cold-pressor analgesia and fingertip hyperalgesia. Together, these results suggest that different aspects of the athletic competition situation might induce analgesic responses in the cold pressor test dependent on sex, whereas the hyperalgesic effects of athletic competition might be caused solely by exercise in both men and women. That cold pressor pain and withdrawal latencies to noxious heat respond in different directions to the experimental manipulations is not surprising, considering the different sensory characteristics of the 2 types of pain. The noxious stimuli presented in the 2 pain tests activate different classes of nociceptors and produce pain sensations with distinct qualities; radiant heat produces a pricking, burning sensation, whereas cold produces pain of an aching quality.[21] The pain inhibitory effects produced by the experimental manipulations in this study appear to be limited to the type of deep tonic pain associated with the cold pressor test.

The cold pressor data revealed overall significant sex differences in pain ratings (on both intensity and unpleasantness scales) during both baseline and activity sessions. That is, women reported more pain during a 90-second immersion in cold water than men. Small but consistent sex differences also were noted for the heat withdrawal measure at both heat intensities on the fingertips, but not on the forearms. Women exhibited significantly shorter withdrawal latencies (indicating lower pain thresholds). In general, when sex differences in pain are detected in clinical settings and experimental investigations in human subjects, men have greater pain tolerance than women.[22,23] It is relatively uncommon to find these human sex differences in pain threshold. More common in humans are observations of sex differences in pain tolerance or pain of a clinical nature,[24,25] and in cold pressor pain,[25,26] in the same direction as those observed in the current study.

One confounding factor in obtaining verbal cold pressor pain ratings from male and female subjects is the gender of the experimenter. Levine and DeSimone[27] noted that men report significantly lower levels of cold pressor pain to female experimenters than to male experimenters. An effect of experimenter gender was observed in the present data, but not one that could account for the overall sex difference reported. Pain ratings of male subjects who were tested by an opposite sex experimenter did not differ from those reporting to a same sex experimenter. However, women reported significantly less pain to an opposite sex experimenter than to a same sex experimenter. This effect is in the opposite direction to that hypothesized by other investigators,[27,28] who suggest that women might report greater pain to male experimenters in an attempt to create conditions of social desirability by adopting a traditional feminine sex role characterized by weakness and sensitivity to pain. The current data suggest that if women are altering their pain report in an attempt to create conditions of social interest, then appearing insensitive to a noxious stimulus might be more socially desirable than appearing hypersensitive (at least among female athletes). Although the interaction was statistically significant and the mean differences were impressive, we are cautious about interpreting these data. Two of the 3 experimenters carrying out this study were women; thus, we did not attempt to assign equal numbers of male and female subjects to either same or opposite sex experimenters. As a result, the sample sizes were highly uneven, and we were unable to include athletic status as an independent variable in the analysis of the female subjects. Experimenter gender will be deliberately examined in future studies investigating the phenomenon of competition-induced analgesia. However, these findings highlight the importance of the social context in interpreting pain report data from human subjects.

Athletes and nonathletes experienced identical analgesic effects from either exercise (women) or sedentary competition (men). Thus, differences in fitness levels between men and women are unlikely to account for the analgesic effect from a short-duration treadmill run in women only. However, athletic status did account for variability in cold pressor ratings averaged across day; nonathletes rated the pain as more intense and more

unpleasant than did the athletes. Athletes are known to show diminished sensitivity to noxious cold and are more tolerant to ischemic stimulation and noxious pressure than nonathletes, but not different in their responses to noxious heat.[26,29-32] The differences in cold pressor ratings between athletes and nonathletes were statistically significant at the first rating report (15 seconds after immersion) although the difference between athlete and nonathlete was most pronounced by the end of the 90-second immersion. The rise in cold pressor ratings was far steeper in the nonathlete subjects than in the athletes, whose ratings did not significantly increase after the 30-second time point. Consistent with this existing literature, there were no differences in withdrawal latencies between athletes and nonathletes; the athletic status differences were limited to cold pressor ratings. The noxious stimuli that athletes are better able to withstand than are nonathletes (ie, noxious cold, pressure, and ischemia) share sensory attributes of tonicity and deepness. This observation might be related to our present demonstration of competition-produced analgesia only on cold pressor pain and not on withdrawal latencies to noxious heat.

The present findings further support the concept that athletic competition is a stressor capable of eliciting an analgesic response and identifies laboratory manipulations sufficient to produce this response in human subjects. The relatively untapped areas of human stress-induced analgesia research in general, and competition-induced analgesia specifically, are ripe for further investigation. Studies such as these emphasize the complexity of the pain experience and suggest future directions for the laboratory study of the psychological factors that can influence pain report.

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